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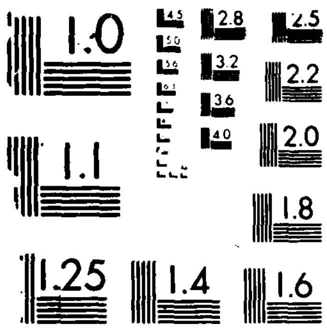

MICROCOPY RESOLUTION TEST CHART

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technical Report

United States Army
Belvoir Research, Development & Engineering Center
Fort Belvoir, Virginia 22060-5606

Report 2453

Developing an Accelerated Endurance Test for Greases—A Status Report

Authored By:

In-Sik Rhee

Report Date:

August 1987

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The objective of this study was to develop a grease endurance test method which can be utilized in the comprehensive test methodologies being developed for predicting the performance life of military grease under laboratory environment. In an initial study, the ASTM D3527 test method, "Life Performance of Automotive Wheel Bearing Grease" has been evaluated because it is supposedly simulating an operating environment and has widespread applications. The results show that this method has poor precision, long-endurance test time and poor simulation of field conditions. In particular, the termination criteria used in this method tend to extend grease life. To solve the problem, tentative termination criteria were developed based on the softening of grease, which reduced the test time and distinguished between a good and a poor grease as well as the current method is able to do. To define the L10 life of MIL-G-10924 grease, baseline tests were conducted using the ASTM D3527 method. The L10 life of this grease is less than 20 h. Such a grease is not satisfactory in military vehicles with wheel bearings that are equipped with disc brakes.

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Section I. INTRODUCTION

The US Army is presently using a multi-purpose National Lubricating Grease Institute (NLGI) Number 2 consistency grease covered by Military Specification MIL-G-10924D, "Grease Automotive and Artillery (GAA)," as the standard grease for all Army vehicles, artillery, and ground equipment operated worldwide.[1] With rapid advances in automobile technology, the operational and system requirements of military vehicles and equipment have imposed demands for increased capabilities of the lubricating greases. To meet these additional requirements, research is being conducted to develop new performance criteria that will be required for the "E" revision to MIL-G-10924. One of the major thrusts in executing this research effort is the development of comprehensive test methodologies which can be utilized to predict performance life of these military greases.

A project was initiated to develop a methodology for predicting the L10 life of grease products under a laboratory testing environment. The L10 life value is a means of defining the minimum life and is an expression meaning the 90 percent reliable grease life in bearings. A research plan was subsequently established for the following three phases:

Phase I: Develop the mathematical modeling system to evaluate functional performance of grease products.

Phase II: Select or develop accelerated endurance testing method(s).

Phase III: Correlate laboratory test methodology with field performance.

In one of our previous research efforts, the maximum likelihood (ML) computer program for the two-parameter Weibull probability distribution was developed to meet the primary objective of Phase I.[2] To provide meaningful input data, the current research effort is directed toward developing the grease endurance testing procedure which is planned in Phase II.

For the last three decades, numerous ball-bearing and roller-bearing grease endurance tests have been devised for laboratory evaluation of grease. Some of them were used to standardize specific test procedures in the grease industry, while others were used in individual laboratories for grease development. Among these standard methods, the American Society for Testing and Materials (ASTM) D3527 test method, "Life Performance of Automotive Wheel Bearing Grease," is widely used in the grease manufacturing and automotive industries. Because of its application and simulation of an operating environment, a study was conducted to evaluate the ASTM D3527 method prior to being incorporated into MIL-G-10924D. This report describes the advantages and disadvantages of this method, our findings, and the results of a feasibility study conducted to develop an accelerated endurance test using this method.

Section II. OVERALL REVIEW OF ASTM D3527 METHOD

The method covers a laboratory procedure for evaluating the high-temperature (160 °C) ASTM D3527 under specified conditions. The significance of this method is that it differentiates among wheel bearing greases having distinctly different high-temperature characteristics only. The current precision is as follows:

Repeatability = 0.8 X
Reproducibility = 1.2 X
Where X = average of the two test results

The basic configuration of the test apparatus consists of a simulated front wheel hub-spindle-bearings assembly, a heater, a dc-motor, a tachometer, an elapsed time meter, a torque meter, and a temperature monitor. Two tapered roller bearings were used as the test specimens in this procedure: LM67048-LM67010 for the inboard bearing, and LM11949-LM11910 for the outboard bearing. Both bearings are currently utilized in small vehicles. For the test, three main parameters (temperature, load, and speed) were applied to this method. Initially, a test temperature of 150 °C was selected at the outboard bearing because wheel bearing temperatures associated with front disc brake systems higher than 150 °C were encountered.[3] In 1985, the test temperature was raised from 150 to 160 °C at the outboard bearing to provide a more severe test condition. The test speed selected was 1,000 rpm. The thrust load of only 25 lb_f (representing the vehicle curb and axial cornering weight) was applied to the test bearings because the test apparatus developed was based on modifications of the ASTM D1263, "Leakage Tendencies of Automotive Wheel Bearing Grease," method.[4] This preload was adapted from a wheel bearing adjusting nut torque value used in light trucks. With these test parameters, grease life was determined when the drive motor torque exceeded a preset torque limit for 30 seconds in 20 hours on, 4 hours off cycle operation.

The advantage of this method was to comprehensively evaluate all individual physical properties of greases directly related to high temperature and shear, using a simulated front wheel bearing system and a dynamic laboratory bench-type test apparatus. The disadvantage of this method was its poor precision. For this reason, this method did not have the capability to distinguish between the greases having similar high-temperature properties. Finally, the test results provided limited correlation to field performance.

Since this method was issued, it had not been extensively utilized in grease research and development and specifications because of its poor precision, long endurance test time, and questionable correlation with field vehicle operation conditions. The ASTM Committee D2 Subsection B0.04 on Automotive Greases is currently developing a Chassis Grease and Wheel Bearing Grease specification to cover lubricating grease suitable for the periodic relubrication of commercial vehicles.[5] In this wheel bearing specification, the ASTM D3527 method is listed with its minimum requirement (80 hours). Due to the method's poor precision, the following paragraph is included to justify this requirement:

"The test requirements (limits) given in this specification are, as the case may be, minimum or maximum acceptable values for valid duplicate test results. No additional corrections for test precision, such as described in the ASTM D3244, "Utilization of Test Data to Determine Conformance with Specifications," are to be applied inasmuch as the precision of the test methods were taken into account in the determination of the requirements."

However, the US Army currently uses a modified version of ASTM D3527 in the MIL-G-10924 specification without the above reservation. The currently identified problem areas are the termination criteria and the test temperature measurement technique.[6,7] According to the ASTM D3527, the test temperature is measured from the spindle hole in which the thermocouple is inserted, resulting in a temperature gap of 20 to 30 °C between the chamber and spindle. It appears that the test temperature is closer to the chamber temperature instead of the spindle temperature because the test specimen (wheel bearing hub system) is fully open in the chamber and the heat transfer is facilitated by hot air in the chamber. Therefore, the actual test temperature is assumed to be higher than 160 °C.

The problems associated with the ASTM termination criteria used in this method are:

- As a consequence of the cyclic operation, the resulting grease life is probably longer than the actual life of the grease.
- Test results are unrepeatable.
- Since the torque rarely reaches the preset torque limit, there is a termination problem.
- The test is terminated at room temperature rather than the test temperature.

The termination profile of the ASTM D3527 method is shown in Figure 1. These problems directly affect precision. To solve these problems, the ASTM G0.05 Subsection is studying possible modification to this test machine. Ever since this method has been issued, there have been informal reports of frequent equipment problems.

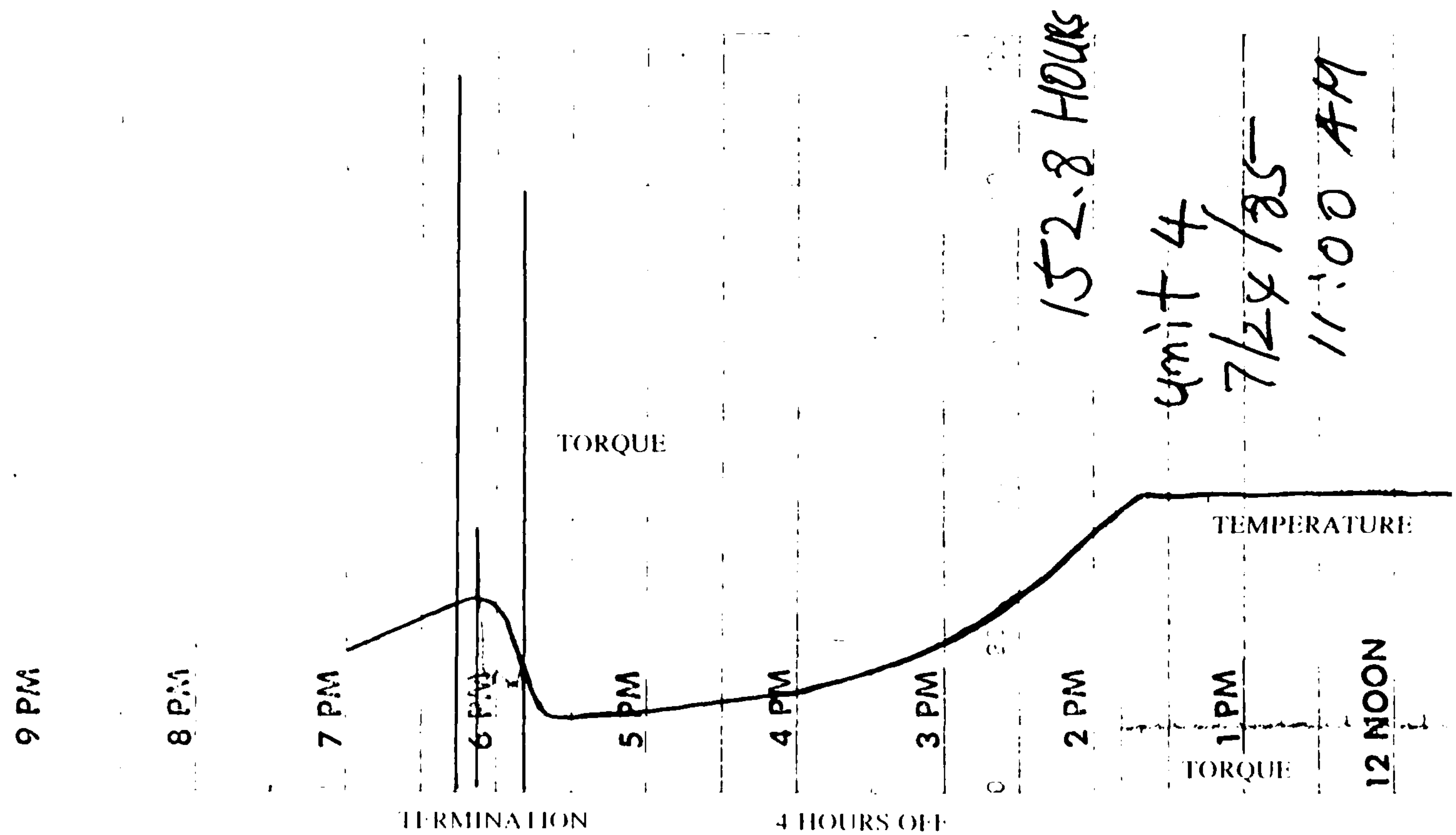

Figure 1. Termination Profile of the ASTM D3527 Method

Section III. THE LOADING REQUIREMENT ON THE ASTM D3527 METHOD

The primary objective of this study was to establish a comparative baseline for loading requiements (i.e., test severity) of the three major test parameters (temperature, loads, and speed) to be used in the laboratory grease endurance test procedure. The equipment targeted for use in developing this wear-life projection was the ASTM D3527 test apparatus. Because of questions concerning test parameters, the major focus on this apparatus was the radial load (vehicle weight) which had been used as a test parameter in previously conducted grease investigations using the SKF grease test procedure.[8,9,10]

For this reason, a study was conducted to determine whether the radial load should be considered as a test parameter in the grease endurance test procedure. This task was performed using the differences of two test methods (ASTM, SKF). The major differences of these methods were the load treatment on the test bearing, termination criteria, and test operation (continuous vs. cycle operation). To make a comparison, the grease endurance tests were performed according to the Modified ASTM D3527 test method. The grease used in these tests was a qualified MIL-G-10924C grease evaluated previously using the SKF grease test method. Table 1 presents test conditions.

Thirteen data points were generated using the four ASTM D3527 test devices. Due to the poor precision, the MIL-G-10924C "grease life" was determined using the ML computer program. The L10 life of the MIL-G-10924C grease was projected to be 238 hours. This L10 life value was approximately eight times longer than that previously obtained from the SKF method which gave an L10 life of 32 hours. This implied that the grease life also depends on the load as well as the temperature. Therefore, the results indicated that the radial load (vehicle weight) should be used as a test parameter in the grease performance test. These test results are plotted to make a comparison in Figure 2, and their test results are provided in Figures 3 and 4.

Table 1. Grease Endurance Test Conditions in the Modified ASTM 3527 Method and the SKF Method

	Modified ASTM	SKF
Test temperature	121 °C	121 °C
Speed	800 rpm	800 rpm
Thrust load	25 lb_f (fixed)	560 lb_f (applied each 5 minutes for 90 seconds duration)
Radial load	none	1,875 lb_f (fixed)
Test bearings	Tapered roller bearing	same as ASTM
Operation	Cycle (20 hours on, 4 hours off)	continuous
Termination criteria	Torque	Vibration, Time-up, Noise, Temperature

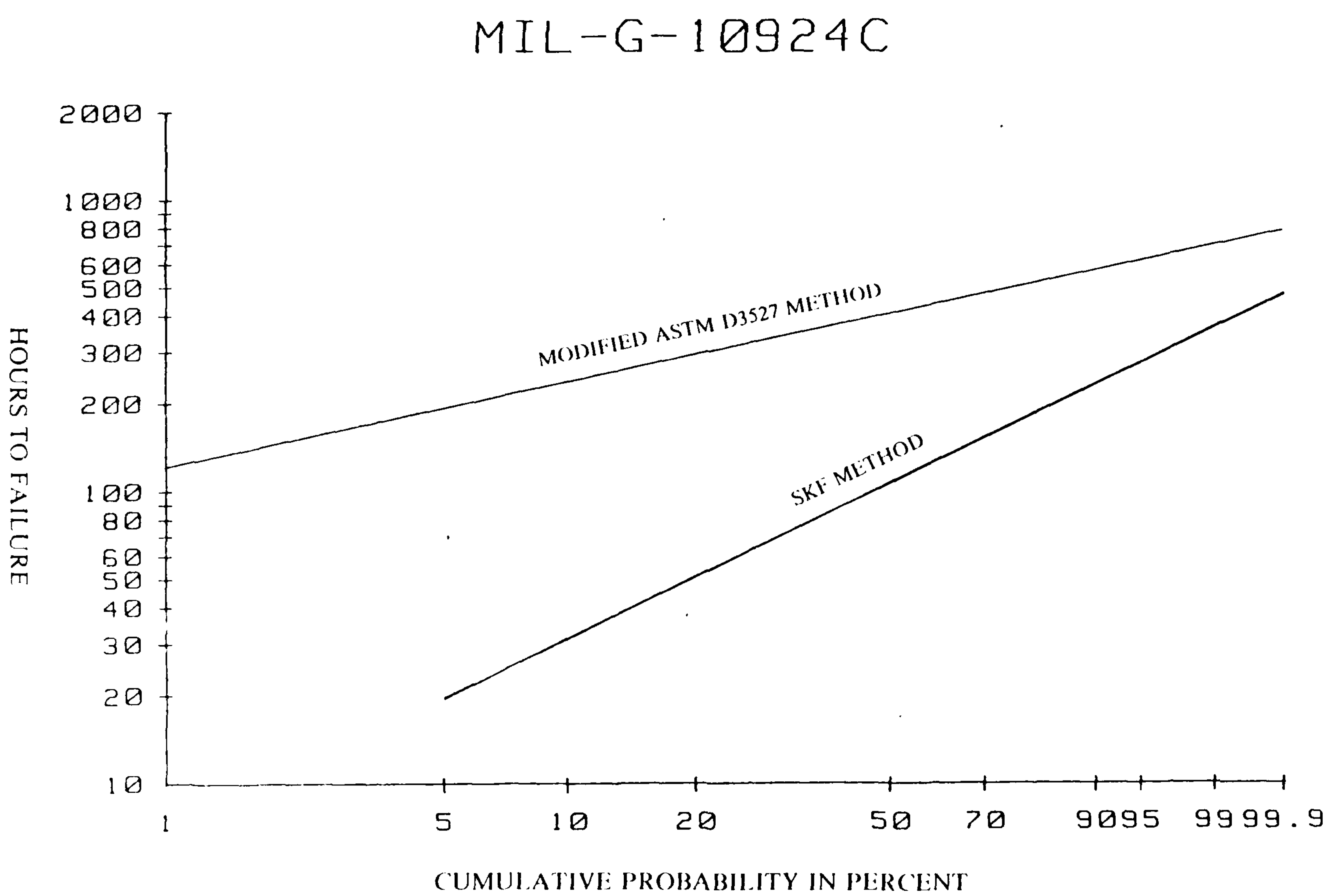

Figure 2. Life of MIL-G-10924C Grease at Two Different Loading Systems

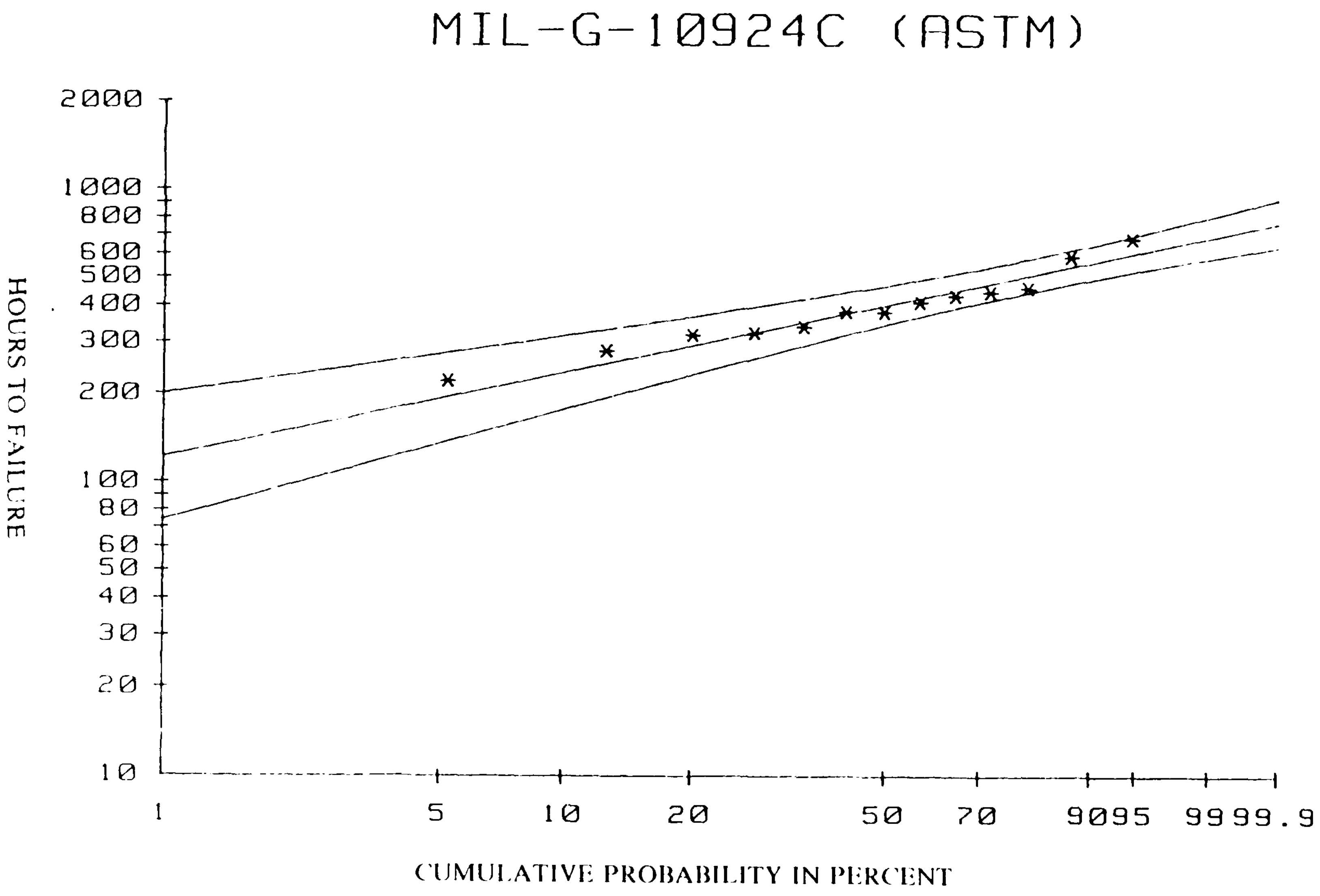

Figure 3. Life of MIL-G-10924C Grease in the Modified ASTM D3527 Method

ESTIMATES FOR THE CUMULATIVE WEIBULL DISTRIBUTION

F(X) = 1 - EXP(- (X/A) ^ B)

ESTIMATE AND TWO-SIDED 90% CONFIDENCE INTERVALS
FOR DISTRIBUTION PARAMETERS

SHAPE (BETA) PARAMETER = 3.5328
LOWER LIMIT = 2.5310
UPPER LIMIT = 4.9310

SCALE PARAMETER = 449.9063
LOWER LIMIT = 392
UPPER LIMIT = 516.0136

ESTIMATED COVARIANCE MATRIX OF PARAMETER ESTIMATES

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SCALE	1405.8787	9.0111
SHAPE	9.0111	.5128

ESTIMATE AND TWO-SIDED 90% CONFIDENCE INTERVALS
FOR DISTRIBUTION PERCENTILES

PERCENTAGE	PERCENTILE ESTIMATE	LOWER LIMIT	UPPER LIMIT
1.0	122	74	201
5.0	194	137	276
10.0	238	178	318
20.0	294	234	370
50.0	406	348	472
70.0	474	415	541
90.0	570	499	651
95.0	614	533	707
99.0	693	589	815
99.9	778	644	938

L10

LCL	MED	UCL
178	238	318

L50

LCL	MED	UCL
348	406	472

Figure 3. Continued

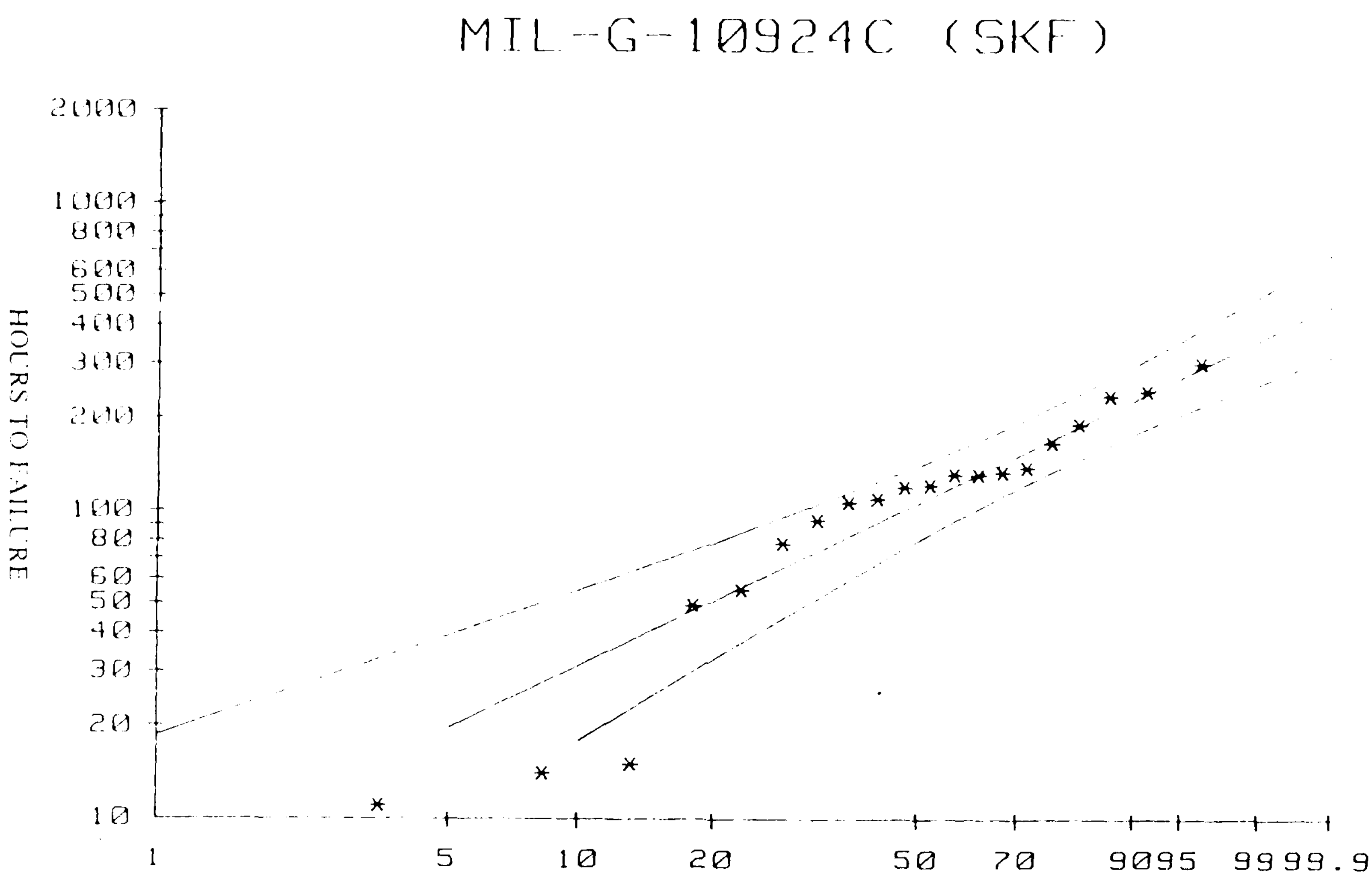

Figure 4. Life of MIL-G-10924C Grease in the SKF Method

ESTIMATES FOR THE CUMULATIVE WEIBULL DISTRIBUTION

F(X) = 1 − EXP(− (X/A) ^ B)

ESTIMATE AND TWO-SIDED 90% CONFIDENCE INTERVALS
FOR DISTRIBUTION PARAMETERS

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UPPER LIMIT = 2.0943	UPPER LIMIT = 172.7830

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SHAPE	1.7054	.0804

ESTIMATE AND TWO-SIDED 90% CONFIDENCE INTERVALS
FOR DISTRIBUTION PERCENTILES

PERCENTAGE	PERCENTILE ESTIMATE	LOWER LIMIT	UPPER LIMIT
1.0	7	3	19
5.0	20	10	40
10.0	32	18	55
20.0	51	33	79
50.0	106	81	140
70.0	152	120	193
90.0	231	179	297
95.0	274	208	360
99.0	361	261	500
99.9	469	319	689

L10

LCL	MED	UCL
18	32	55

L50

LCL	MED	UCL
81	106	140

Figure 4. Continued

Section IV. NEW TERMINATION CRITERIA FOR THE ASTM D3527 METHOD

The current grease failure criteria used in the ASTM D3527 method originally were developed based on a hardening of grease which, in turn, produced lubricant starvation. However, it now appears that these criteria can only be utilized when the running torque value has a higher value than a steady-state torque value which developed at the first 2 hours of operation. In practice, the running torque value does not always produce a higher value than its initial value measured at 2 hours of operation. In our previous tests, evidently, it was observed that the MIL-G-10924C grease sample underwent changes at 121 °C in two distinct stages. In the first stage, the grease appeared to soften or become semifluid at the given test temperature and speed. The running torque observed at this stage was about a quarter of the steady-state torque obtained at the first 2 hours of operation; then, hardening of the grease occurred in the later stage. To provide more evidence, a lubrication comparison test was conducted using the modified ASTM D3527 method used in the MIL-G-10924C grease endurance tests. The lubrication used in this comparison test was the VV-L-800, "General Purpose Preservative Oil," having similar property as the base stock used in the MIL-G-10924C grease.[11] The results showed that the lubrication life marked 9.3 hours, and the running torque value was almost identical to that obtained with the MIL-G-10924C grease. It would appear that the grease in question changed its consistency during the test due to the temperature and shear forces incurred in the first stage. These physical property changes may affect grease endurance life and lead to subsequent bearing failure. Generally, the deterioration of grease results from oxidation reactions, a breakdown of grease structure, excess bleeding or separation of oil from the thickener, and contamination.[12] These physical property changes can all be considered as grease failure criteria.

To develop new termination criteria for the ASTM D3527 method, a feasibility study was conducted using a candidate grease for the "E" revision of MIL-G-10924 Specification and the MIL-G-10924C grease used in the SKF tests. The former is a high dropping point grease, whereas the latter is a low dropping point grease. The physical and chemical properties of these greases are shown in Table 2. For the feasibility study, the following tentative termination criteria were developed based on the softening of grease indicated in the previous test results:

TC = M (ST - N) [illegible] N, *where*
M = [illegible]
ST = steady-state torque value obtained at 2 hours operation
N = to[illegible]que of unloaded motor
Holding time for TC = 30 seconds

To make a comparison, grease endurance tests were performed using both current ASTM termination criteria (high set point) and the tentative new termination criteria (low set point) at 121 °C and 160 °C. The test results are shown in Table 3.

Table 2. The Physical and Chemical Properties of Tested Greases

Test	ASTM Method	Grease: MIL-G-10924C	Grease: Candidate Grease for MIL-G-10924E
NLGI Consistency Number:			
Worked 60X	D217	2	1½
Unworked	D217	—	3½
Thickener Type:		Calcium	Lithium Complex
Base oil		Petroleum	Polyalphaolefin
Base oil viscosity at 40 °C, cSt		13.3	220
Cone Penetration (worked 60X):	D217	281	305
Dropping Point, °C:	D2265	143	260 +
Oil Separation, %:	D1747	5.2	0.62
Evaporation, %:	D972	5.3	1.72
Oxidation:			
Stability, 100 hours	D942	2	2
4 Ball EP, LWI	D2596	35.8	50

Table 3. Grease Life in Both Termination Criteria

Test Temperature	MIL-G-10924C		Candidate Grease for MIL-G-10924E	
	LSP*	HSP**	LSP	HSP
120 °C	80 hours	150 hours	—	>1,000 hours
160 °C	—	>20 hours	57.9 hours	123.8 hours

* LSP: Low set point

** HSP: High set point (current ASTM D3527 termination criteria)
ASTM termination criteria:
TC = 8 (initial torque − unloaded torque) + unloaded torque
Holding time for TC: 30 seconds

The candidate grease for MIL-G-10924E Specification did not follow either termination criteria at 121 °C. It appeared that the test temperature (121 °C) may be too low to fully stress or deteriorate the high dropping point grease. This grease was terminated by both set points when tested at 160 °C. The grease terminated by the low set point criteria appeared to be moderately oxidized and dried with free oil. On the other hand, the failed grease detected by the high set point criteria appeared to be completely oxidized and only residue grease remained in the bearings. The life obtained using the low set point criteria was approximately one half of that obtained when using the high set point criteria. In the other test, the MIL-G-10924C grease (low dropping point grease) also followed both set points at 121 °C. The condition of this grease in both tests was similar to the condition of the high dropping point grease. At 160 °C, this grease only operated for 20 hours. However, the actual "life" of this grease was less than 20 hours because most grease failures were observed at the initial cycle operation after a 4-hour rest. Therefore, the minimum life of this method can be considered to be 20 hours. This grease was not suitable to conduct the grease endurance test according to the ASTM D3527 method because of its low dropping point (143 °C). Evidently, the grease completely melted at the test temperature and the tested bearings looked like unlubricated new bearings. Both test results indicated that the tentative termination criteria can reduce the test time to as much as one half of that obtained from the ASTM termination criteria.

To address whether the grease becomes soft or not at the tentative termination criteria, a consistency test was conducted on exposed samples according to the ASTM D1403, "Cone Penetration of Lubricating Grease using One-Quarter and One-Half Cone Scale Equipment." Due to the insufficient amount of grease, only the unworked penetration number of the candidate grease for MIL-G-10924E was determined. The test results showed that the unworked penetration number measured from the used grease (54.4 hours) was softened by a half NLGI number in comparison to that obtained from the new grease. It would appear that the decrease in the running torque at this stage resulted from the combination of softening of the grease and adsorption of certain additives on bearing surfaces. The test results are summarized in Table 4.

Table 4. Consistency Test Results

Grease	Unworked Penetration	
	New	Used (54.4 hours)
Candidate grease for MIL-G-10924	215	238
NLGI Number	3½	3

To define an additional failure criteria for tested greases, experimental oxidation stability tests were conducted using the Pressure Differential Scanning Calorimetry (PDSC) method which is being developed within the ASTM Committee D2 Subsection 09.0E on oxidation.[13] The test results are provided in Figure 5.

The test results showed that the MIL-G-10924C grease used in the modified ASTM D3527 test for 80 hours gave 1.4 minutes in induction time which indicates the relative degree of oxidation in this method. This value was lower than that obtained from the new grease (16.2 minutes) and equivalent to that determined from the heavy oxidized residue grease. The new candidate grease for MIL-G-10924E showed a good oxidation stability at the given test conditions, and the grease used in outboard and inboard bearings for 57.9 hours marked 15.3 minutes and 31.9 minutes respectively. Both values were higher than those obtained from new MIL-G-10924C grease. Although the grease was not oxidized at this stage, the result indicated that the grease was being degraded by the temperature and shear force. Evidently, the induction time obtained from the used grease (57.9 hours) was significantly lower than new grease and higher than the residue grease collected at 123.8 hours.

In summary, the grease lubricated in the outboard bearing gave lower induction time than that obtained from the inboard bearing under the same hub system. This implied that the grease used in the outboard bearing (small bearing) failed earlier than grease obtained from the inboard bearing (large bearing). As the ASTM D3527 method was designed to determine the grease failure life when grease packed in both bearings completely deteriorates, the grease failure occurring in the outboard bearing actually does not signal failure life. Therefore, this developed preliminary termination criteria, based on the oxidation and hardening of grease, intends to extend grease life and sometimes give a termination problem. Based on data developed to date, this method needs new termination criteria which can determine the true grease life. The tentative termination criteria reduced the test time and distinguished a good and poor grease as well as the current method is able to do.

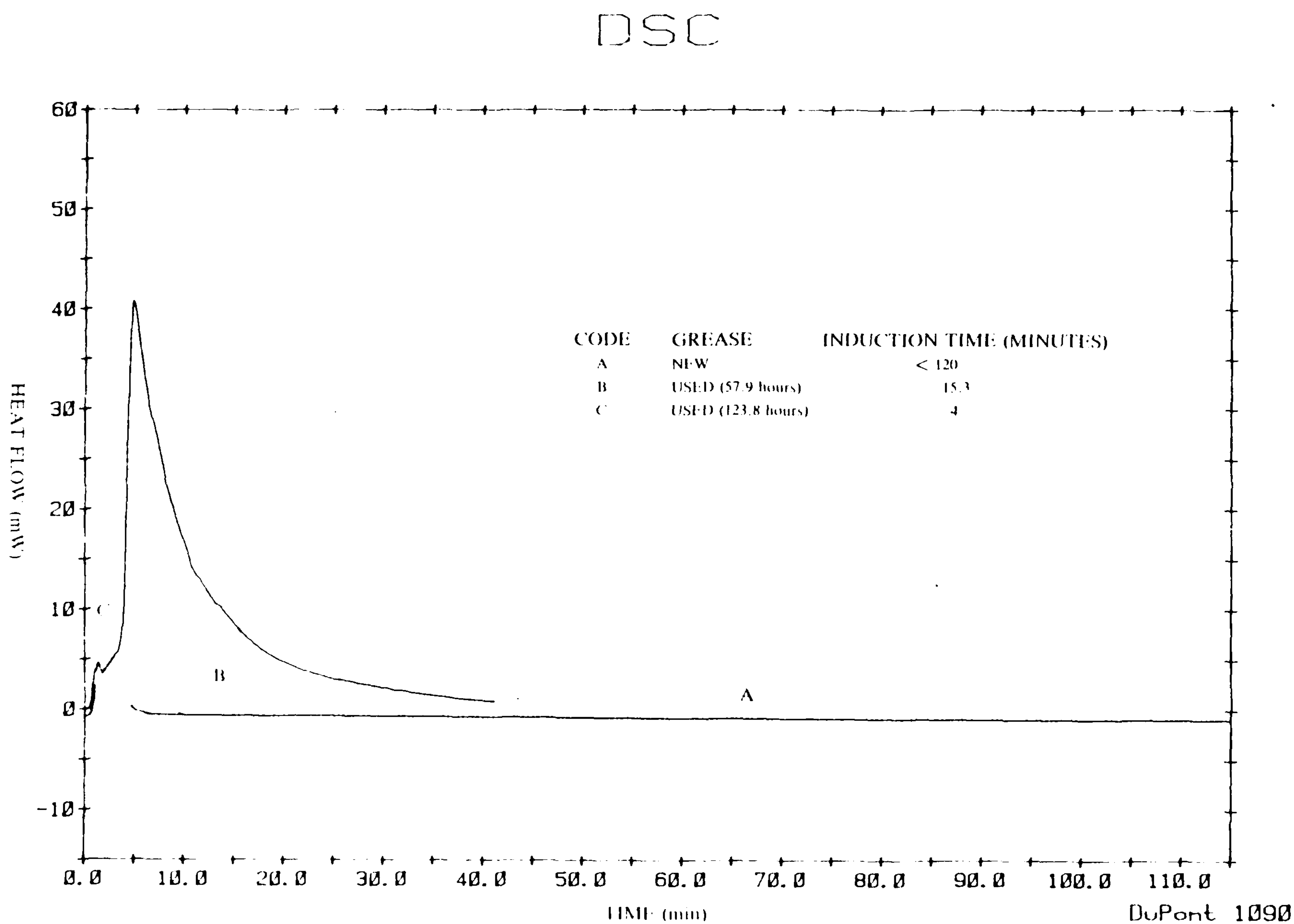

Figure 5. Oxidation Stability Test Results of the Candidate Grease for MIL-G-10924E in the PDSC Method

	MIL-G-10924C					Candidate Grease for MIL-G-10924E				
Grease:	New grease	TTC		ASTM		New grease	TTC		ASTM	
Bearing:		IB	OB	IB	OB		IB	OB	IB	OB
Induction Time (min):	16.2	1.4	—	—	—	120+	31.9	15.3	6.3	4

TTC: Tentative termination criteria
ASTM: ASTM termination criteria
IB: Inboard bearing
OB: Outboard bearing

Figure 5. Continued

Section V. THE REQUIREMENT OF L10 LIFE OF GAA IN THE ASTM D3527 METHOD

To establish the requirement of L10 life of current GAA grease and the future long life Army grease, baseline tests were conducted using the ASTM D3527 method. Of the nine qualified products under the MIL-G-10924D Amendment 1 Specification, only one high dropping point grease was qualified to perform according to the ASTM D3527 method.[14] The other greases were not included in this evaluation due to their lower dropping points (143 °C). Eight data points were generated on the one qualified product and its L10 life was determined using the ML computer program. The baseline grease life, with 90 percent confidence intervals, and its numerical percentile life are shown in Figure 6. The L10 life obtained from this baseline test was 52 hours, and the L50 life (representing the average life) was 116 hours. This L50 life was longer than the requirement of the draft ASTM wheel bearing specification. The average life of conventional wheel bearing greases is between 80 to 150 hours. The current low dropping point greases supplied under the MIL-G-10924D Specification are generally satisfactory for artillery and ground equipment, but not necessarily in disc brake wheel bearing applications because the testing at 160 °C provided a life less than 20 hours.

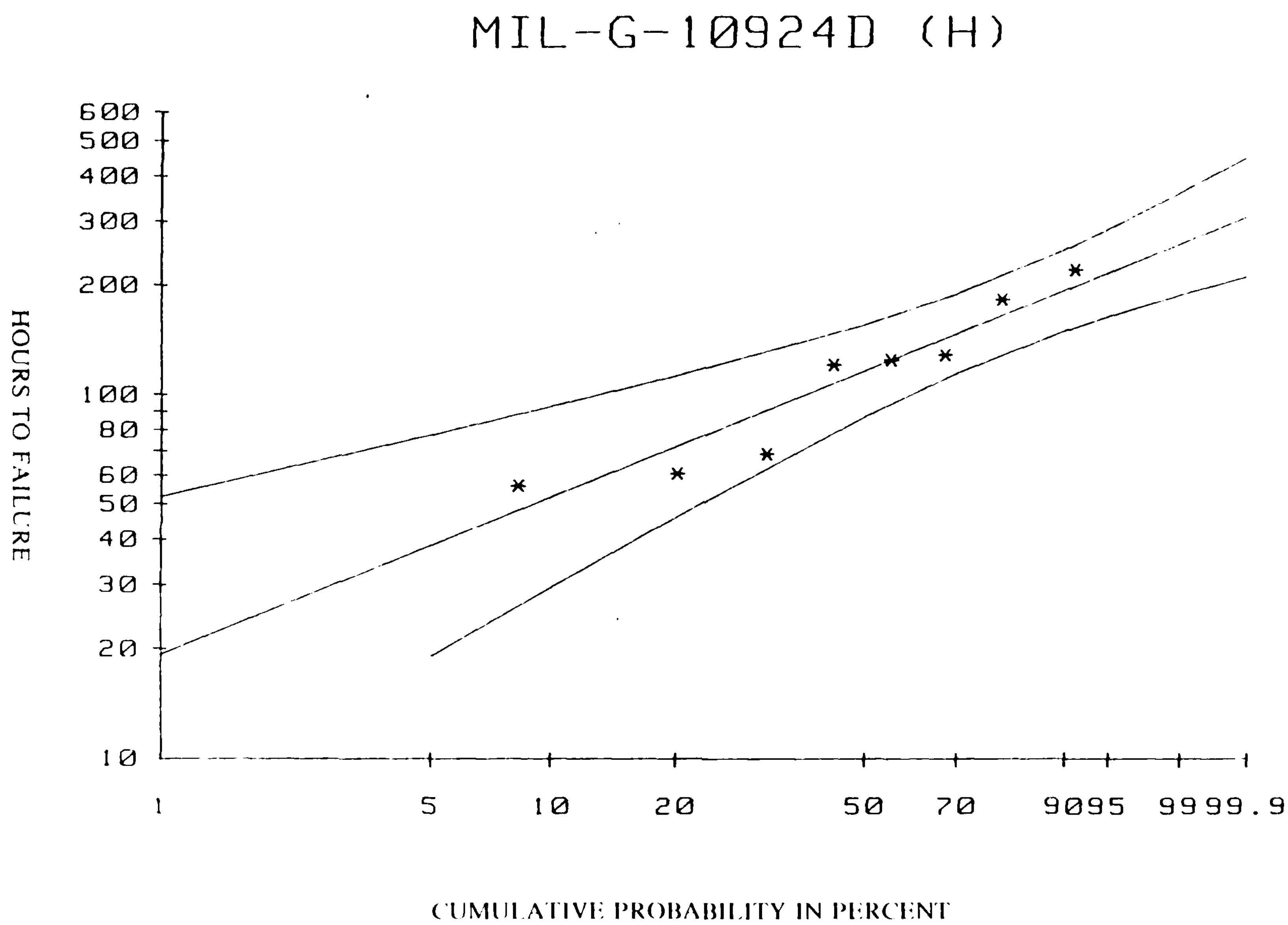

Figure 6. Life of High Dropping Point Grease, MIL-G-10924D

ESTIMATES FOR THE CUMULATIVE WEIBULL DISTRIBUTION

F(X) = 1 − EXP(− (X/A) ^ B)

ESTIMATE AND TWO-SIDED 90% CONFIDENCE INTERVALS
FOR DISTRIBUTION PARAMETERS

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ESTIMATED COVARIANCE MATRIX OF PARAMETER ESTIMATES

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SHAPE	4.5875	.4248

ESTIMATE AND TWO-SIDED 90% CONFIDENCE INTERVALS
FOR DISTRIBUTION PERCENTILES

PERCENTAGE	PERCENTILE ESTIMATE	LOWER LIMIT	UPPER LIMIT
1.0	19	7	53
5.0	39	19	78
10.0	52	30	93
20.0	72	46	113
50.0	116	87	156
70.0	147	114	189
90.0	193	149	250
95.0	216	164	285
99.0	259	188	358
99.9	308	211	448

L10

LCL	MED	UCL
30	52	93

L50

LCL	MED	UCL
87	116	156

Figure 6. Continued

Section VI. DISCUSSION AND CONCLUSIONS

Although the ASTM D3527 method was studied with limited data, it can be concluded that this method may be as good as the screening test, but not applicable to use in the Army grease specification without any modification. The reasons are that this method has poor precision and definition of the meaning of the test. Based on test results, grease life also depends on the load as well as the temperature. Therefore, the radial load should be used as a test parameter with the thrust load.

The current ASTM termination criteria developed based on a hardening of grease gave a termination problem and tended to extend grease life. The new developed tentative termination criteria, based on the softening of grease, reduced the test time as much as one half of that obtained from the current ASTM termination criteria. It also differentiated between a good and a poor grease as well as the current ASTM D3527 does. Results clearly show that this approach resolved the problem associated with the current method. Further study of this termination would be beneficial for developing an accelerated grease endurance method.

The L10 life of high dropping point grease supplied under MIL-G-10924D Specification obtained 52 hours, and L50 life (representing the average life) was 116 hours, which is a longer life than the requirement of the draft ASTM wheel bearing specification (80 hours). The traditional low dropping point MIL-G-10924D grease provided less life than 20 hours. It appears that this grease is not satisfactory in disc brake wheel bearing applications.

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